NONLINEAR STRUCTURAL AND LIFE ANALYSES OF A TURBINE BLADE

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Abstract

The most critical structural requirements that aircraft gas turbine engines must meet result from the diversity of extreme environmental conditions in the turbine section components. Accurate life assessment of the components under these conditions requires sound analytical tools and techniques, an understanding of the component operating environment, and comprehensive data on component materials. Inadequate understanding of any or all of these areas may result in either a conservative life prediction or component failure.

Much activity has occurred in recent years both through Industry and Government programs to provide the designer with the tools for more accurate design analysis and component life prediction. These efforts encompass advances in analytical stress and life prediction techniques, instrumentation capabilities, and cost-effective, accelerated verification testing.

Advanced structural analysis techniques are available to permit more reliable life prediction in the life-limiting turbine components. However, verification of these methods through application to well-documented failure case histories is lacking.

Although nonlinear stress analysis computer programs are available, they have not been used routinely in hot section component design because of the extensive computation time required for such applications. Furthermore, poorly defined material constitutive equations have hampered more general use of such computer programs.

In addition, several high-temperature, low-cycle fatigue, life prediction approaches have been proposed in recent years. These approaches have not yet been applied extensively to hot section components primarily because critical evaluation through application to well-documented failure case histories is needed.

The objective of this program was to evaluate the utility of advanced structural-analysis techniques and advanced life-prediction techniques in the life assessment of hot-section components. A particular goal was to assess the extent to which a three-dimensional cyclic isoparametric finite-element analysis of a hot-section component would improve the accuracy of component life predictions. At the same time, new high-temperature life-prediction theories such as Strainrange Partitioning and the Frequency Modified approaches were to be applied and their efficiency judged.

A commercial air-cooled turbine blade with a well-documented history of cracking in the squealer tip region was selected as the vehicle for accomplishing the above objective. To perform the stress analysis for this turbine blade, a detailed three-dimensional model of the blade tip region was constructed which consisted of eight-noded isoparametric finite-elements (580 elements and 1119 nodes).

To perform the cyclic nonlinear analysis, a commercially available program, ANSYS, was chosen. For this analysis, previously determined temperature-dependent cyclic stress-strain curves and creep data were used. The kinematic hardening option was selected for the plasticity analysis, and the creep analysis was performed with the time-hardening rule. Seven complete cycles were run, at which time shakedown was determined to have occurred. The computed strain-temperature history at the critical location was used to program a thermomechanical test of an axially loaded specimen.

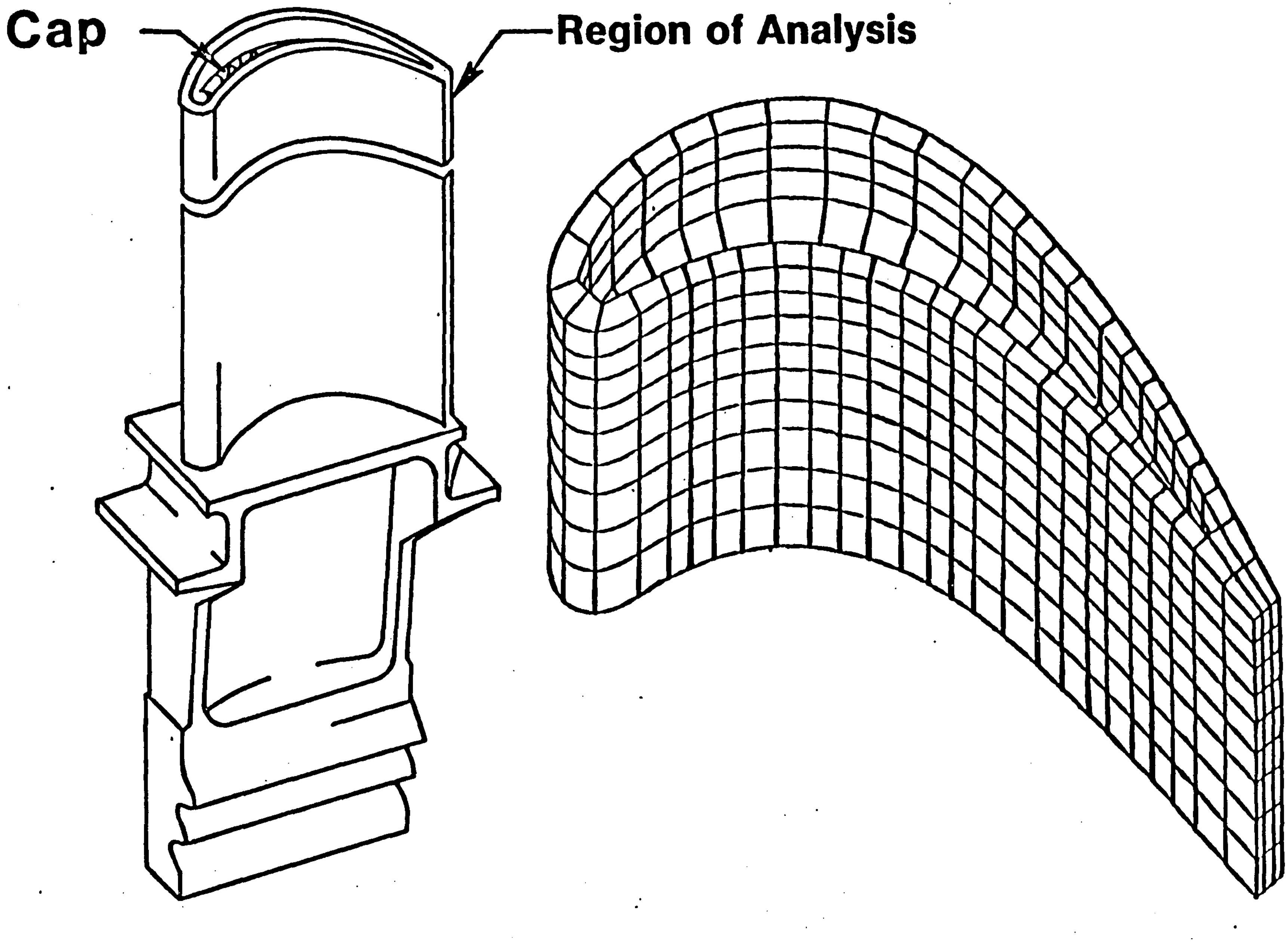
The total strain range at the critical cracking site was calculated using both elastic and inelastic ANSYS analyses. The total strain range values were within less than three percent of each other, thus indicating the potential value of the simpler, much less expensive, elastic analysis. The three dimensional structural analyses produced results in qualitative agreement with the limited experimental evidence. The maximum strain ranges were predicted for the blade tip region where actual cracking occurred.

Tests of a uniaxial strain controlled specimen following the same strain-temperature history as computed at the blade tip crack initiation location showed that the stress-strain response stabilized by the fourth cycle. Analytical simulation of this experiment demonstrated later stabilization of the stress-strain response, higher peak stresses and a smaller amount of stress relaxation than the test results indicated. These discrepancies between analysis and experiment suggest that the creep model and/or data did not accurately represent the material cyclic time dependent behavior.

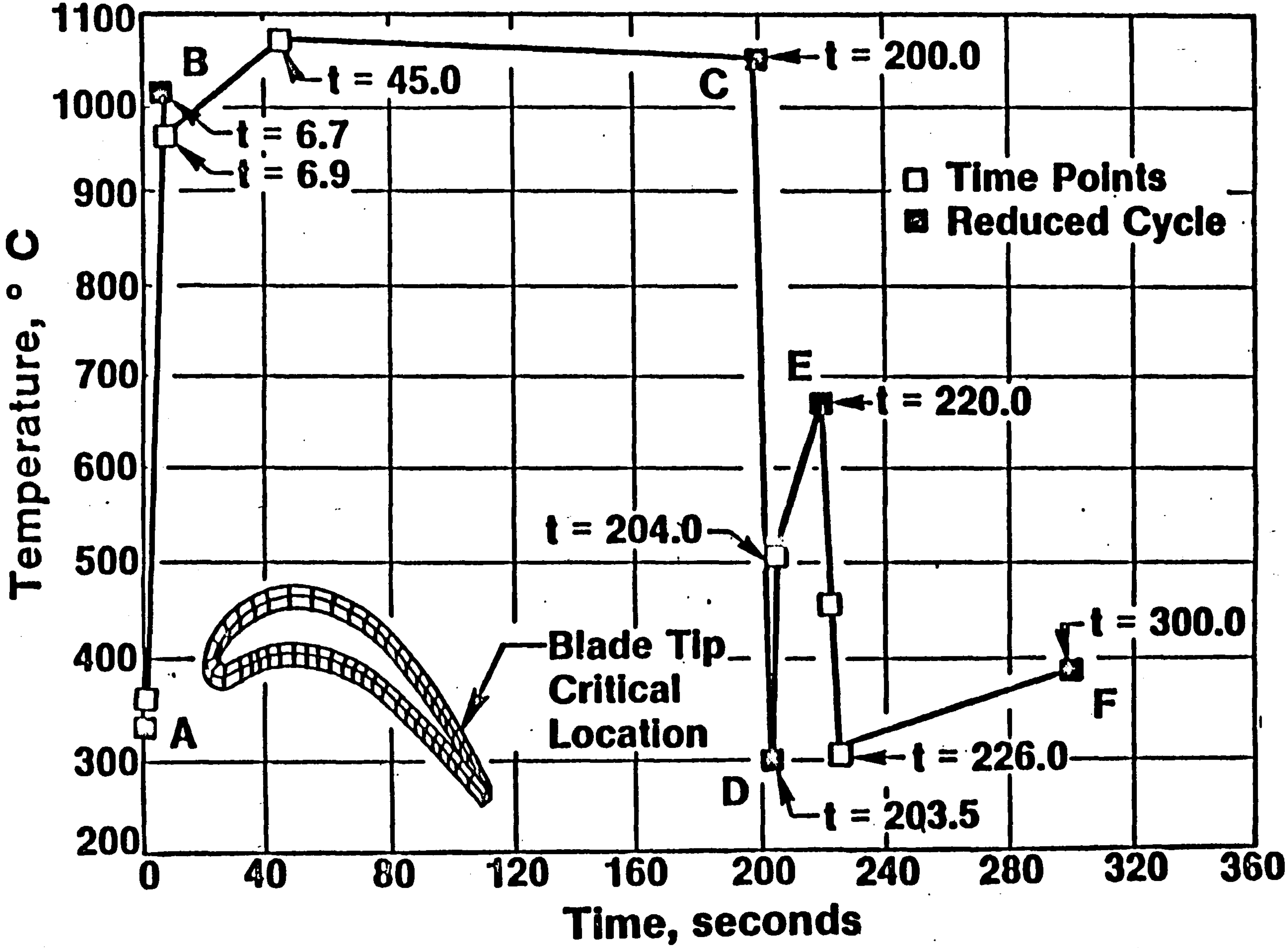
The results of these analyses and the thermomechanical tests were used to make life predictions by several crack initiation life methods, including the Strainrange Partitioning and Frequency Modified Methods.

The evaluation of the life prediction methods indicated that none of those studied were satisfactory. A wide scatter of lives could be predicted with all of the methods because of oversensitivity to input information which was either difficult to calculate accurately or depended on engineering judgements.

Stage 1 High Pressure Turbine Blade and Finite Element Model



Blade Metal Temperature Versus Time at Critical Location



Results of Turbine Blade Tip Structural Analyses

(All Results are for Principal Direction Normal to Radial Crack at Critical Location)

		Inelastic		
	Elastic	Cycle 1	Cycle 2	Cycle 7
Max. Total Strain, %	0.025	-0.05	-0.062	-0.0829
Min. Total Strain, %	-0.2925	-0.3582	-0.371	-0.3918
Total Strain Range, %	0.3175	0.3082	0.3090	0.3089
Mean Stress, MPa	-164.9	-12.9	33.7	80.5

Comparison of Uniaxial Thermomechanical Test and Inelastic Analysis Results